Forward Upgrades in PHENIX

The 2012 RHIC/AGS Annual Users' Meeting
Frontiers of RHIC Physics

Thanks much for input from my colleagues in PHENIX

Kieran Boyle
Joe Seele
Ralf Seidl
Richard Seto
Paul Stankus

Matthias Grosse Perdekamp
University of Illinois

June 13, 2013

Content

- **History of PHENIX Forward Upgrades**
  - ➔ Long record of successful staging significant instrumentation upgrades and pooling resources from DOE, NSF, foreign collaborators and institutions
- **Forward Physics Goals for sPHENIX**
  - ➔ Brief: Spin, cold nuclear matter, what will be known ?
  - ➔ sPHENIX physics goals
- **Layout of the sPHENIX forward upgrade**
- **Next steps**

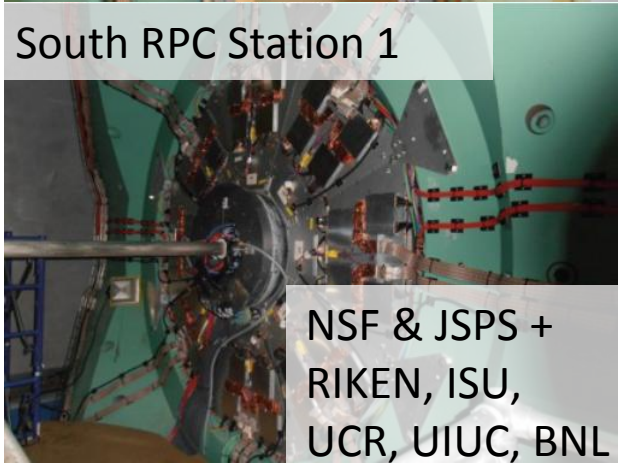
History of PHENIX (Forward) Upgrades

2000	Central Arms	Initial installation
2002	South Muon Arm	Initial installation
2003	North Muon Arm	
2004	Aerogel	PID, hadron spectra
2005	TOF-West	PID, hadron spectra
2006	RXP	Reaction Plane
	MPC	d-A, A_N, A_{LL} di-hadron
2008	HBD	PID, low mass di-leptons
2011	VTX	c-, b-tagging, central tracking
2012	μ-Trigger	W-physics
	FVTX	c-, b-tagging
2014	*MPC-EX*	*π^0-photon separation*

Significant track record with staging instrumentation upgrades and attracting significant resources from outside DOE: NSF, funding sources in Japan, Russia, France, Germany, Israel, Korea, Brazil, China and institutional contributions

Forward Upgrades Completed for Run 2012

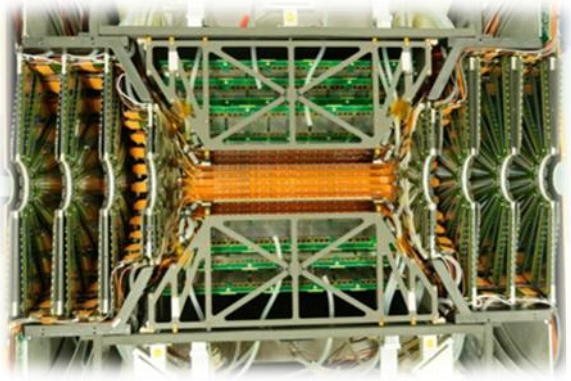
(I) Muon Trigger for W-physics in polarized p+p at √500 GeV



NSF & JSPS + RIKEN, ISU, UCR, UIUC, BNL

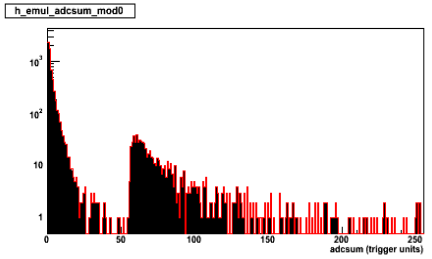
(II) Forward Vertex Tracker for heavy flavor physics in pp, pA, AA

FVTX



DOE, Los Alamos, BNL

(III) MPC FEE/Trigger Upgrade for forward spin measurements

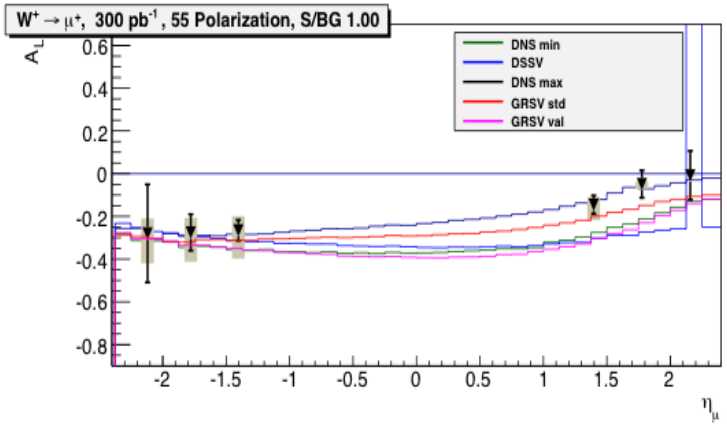


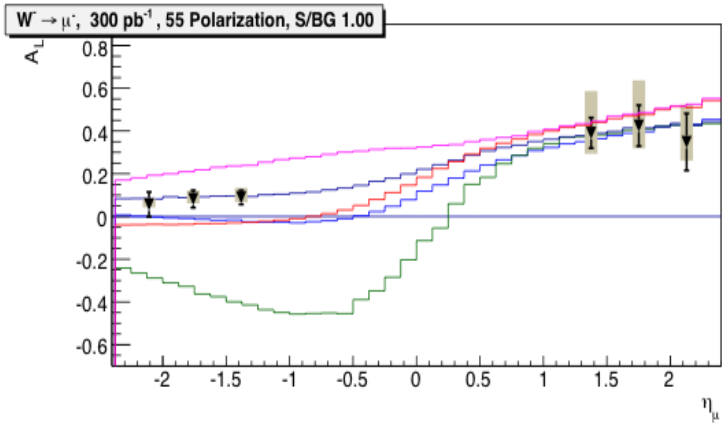
PHENIX-HBD, BNL

Forward Upgrades Completed for Run 2012
➔ Selected Physics Channels

(I) Muon Trigger for W-physics

➔ quark and anti-quark helicity dis.





(II) Forward Vertex Tracker for

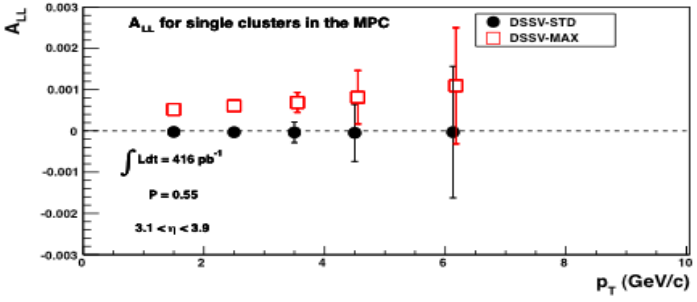
➔ spin asymmetries with flavor tag!

(a) Flavor tagging for heavy quark Physics in pp, pA and AA

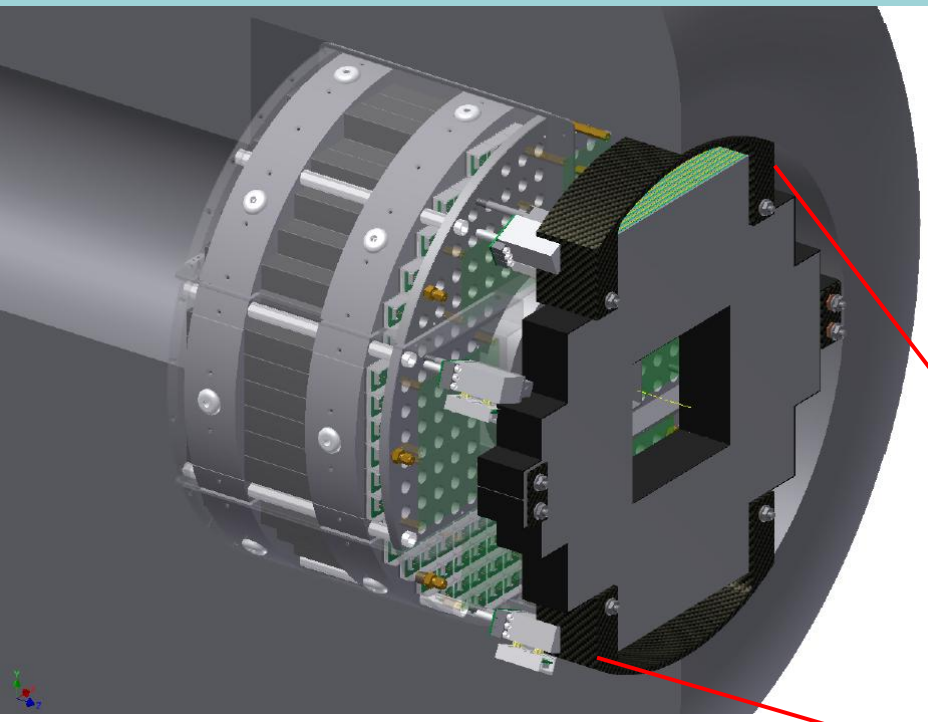
(b) Background rejection for Drell-Yan and W-measurements.

(III) MPC FEE/Trigger Upgrade

➔ probe ΔG(x) at small x



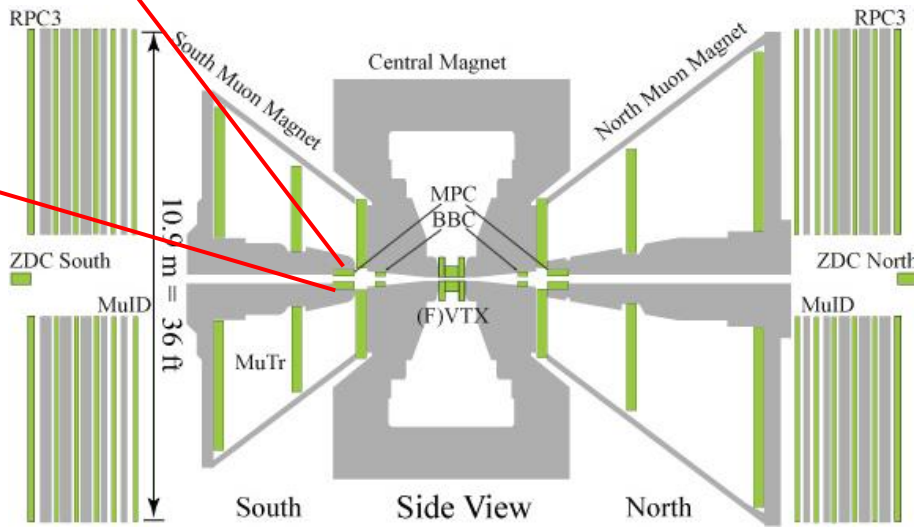
MPC-EX Upgrade aims for Run 2014



$3.1<\eta<3.8$

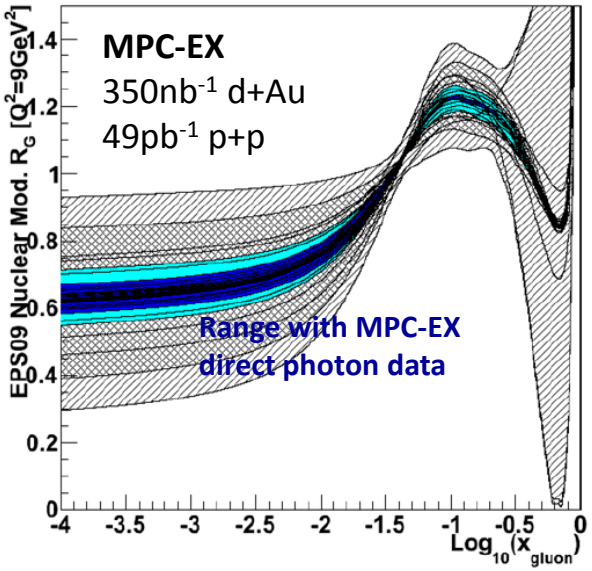
A combined charged particle tracker and EM pre-shower detector – dual gain readout allows sensitivity to MIPs and full energy EM showers.

- π^0 rejection → direct photons
- π^0 reconstruction out to >80GeV
- Charged track identification



MPC-EX Upgrade Physics Goals

(I) Measure nuclear gluon distribution from direct photon production in d+Au collisions



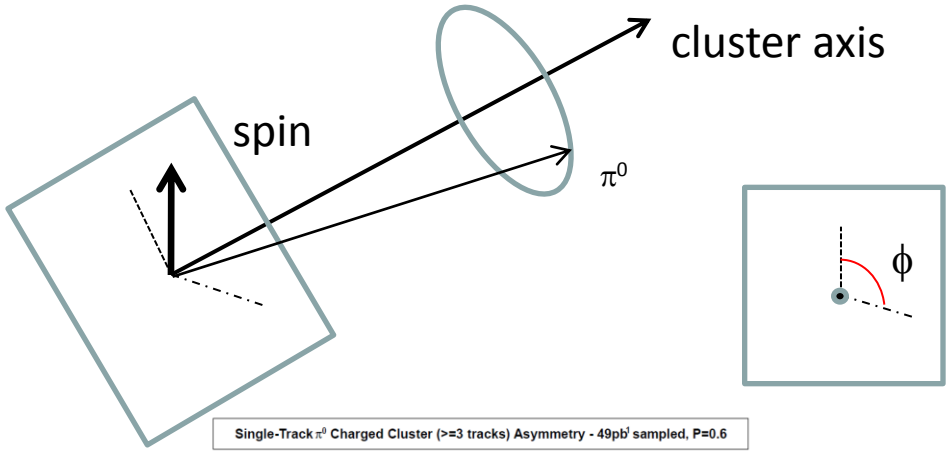
Central curve is

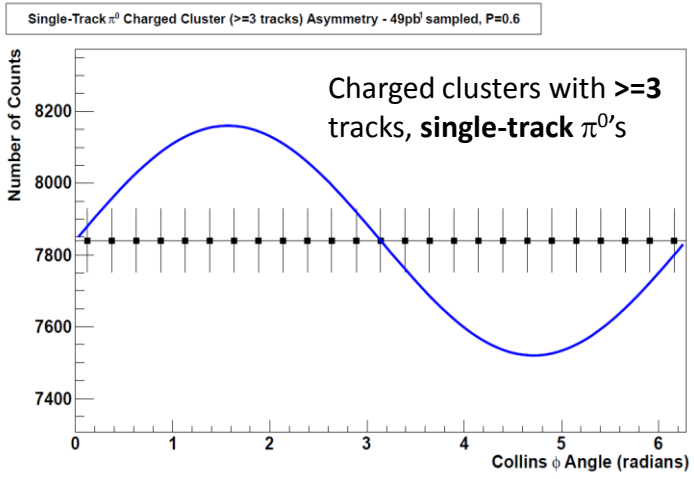
$G_{Pb}(x,Q^2)=R_G^{Pb}(x,Q^2)\,G_p(x,Q^2)$

with grey uncertainty bands from

K. Eskola H. Paukkumen, C. Salgado Nucl.Phys. A855 (2011)150 → EPS09

(II) Determine quark Transversity/Collins contribution to single transverse spin asymmetries A_N in polarized p+p collisions





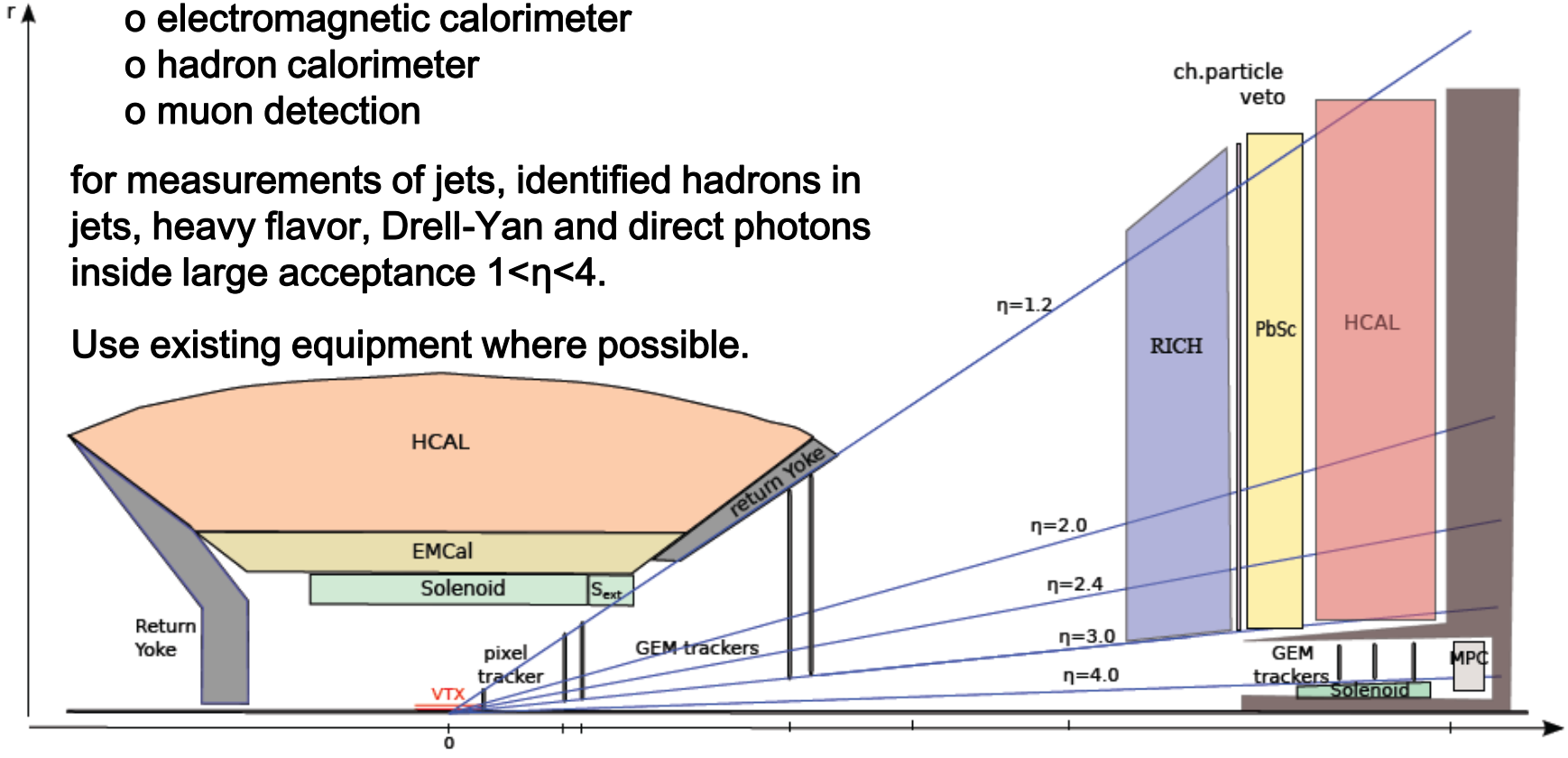
Scope of Possible Forward Upgrade of a Future sPHENIX Detector

Detector Layout for forward physics studies.
Use open sPHENIX geometry to introduce

- o tracking
- o charged particle identification
- o electromagnetic calorimeter
- o hadron calorimeter
- o muon detection

for measurements of jets, identified hadrons in jets, heavy flavor, Drell-Yan and direct photons inside large acceptance 1<η<4.

Use existing equipment where possible.



Forward Physics: What will be known ?

Cold Nuclear Matter Effects in Nucleon Structure:

(I) CNM effects at LHC energies will be firmly established through p+Pb collisions in inclusive hadron-, jet-, di-jet- and heavy flavor-channels.

(II) RHIC experiments will have measured the nuclear gluon distribution for one nucleus through direct photon production.

(III) RHIC has studied CNM effects (and will add more data) through inclusive hadron-production, di-hadron correlations and heavy flavor-channels.

Heavy Ion Physics:

(I) Forward RHIC data sets.

(II) Detailed studies at LHC energies will be available.

Forward Physics: What will we know ?

Nucleon Spin Physics:

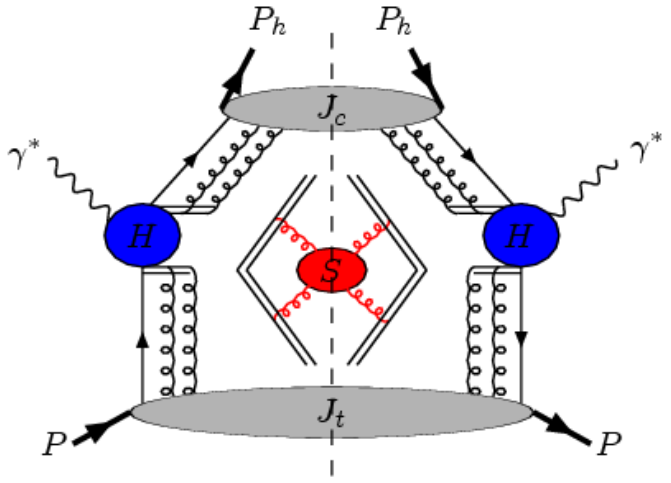
(I) Measurements of quark and anti-quark helicity distributions in W-production further supported by new results from COMPASS and J-Lab12 → NSAC milestone for hadron physics HP8, 2013.

(II) Determination of the gluon spin contribution to the proton spin for $0.01 < x_{gluon} < 0.3$ from A_{LL} measurements for inclusive hadrons, jets and di-jets at RHIC → NSAC HP12, 2013.

(III) Precise measurements of single transverse spin asymmetries, A_N at RHIC. Collins and Sivers effects will be established separately in ep and pp (based on current and future results from RHIC, COMPASS & J-Lab12). COMPASS sign change observation likely in pion induced Drell-Yan → NSAC HP13, 2015.

sPHENIX Forward Physics

The study of transverse spin asymmetries has led to an advanced understanding of scattering processes involving the strong interaction:



TMD framework: inclusion of final and initial state gluon radiation via gauge link integrals gives rise to large transverse spin effects and process dependence.

The PHENIX forward upgrade aims to

(1) quantitatively confirm TMD framework including decomposition of A_N observed in pp, process dependence and evolution.

(2) measure quark transversity dis. including large x → tensor charge !

(3) measure valence and sea-quark Sivers distributions
→ explore connection to L_z
(M. Burkhard arXiv: 1205.2916v1)

(4) Survey cold nuclear matter effects in the transition region to the saturation regime. Quantify the initial state for HI-Collisions.

Unique measurements at forward rapidity using jet observables and the Drell-Yan process!

Transverse Momentum Dependent PDFs & FFs: Transversity-, Sivers-PDFs and Collins FF

Transversity : Correlation between transverse proton spin and quark spin

$h_{1T,q}(x, k_\perp^2)$

$S_p - S_q$

Sivers : Correlation between transverse proton spin and quark transverse momentum

$f_{1T}^{\perp q}(x, k_\perp^2)$

$S_p - k_{T,q}$ (L_q?)

Collins : Correlation between transverse quark spin and hadron transverse momentum

$H_1^\perp(z, p_\perp^2)$

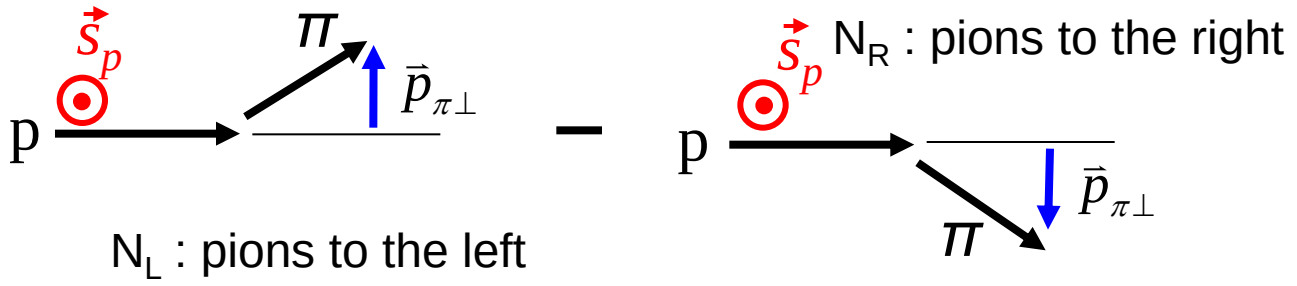
S_q-- $p_{T,h}$

Single Spin Asymmetries (SSA) A_N in Polarized PP: Can we Account for Origin?

Example:
Inclusive π production in polarized p-p

$$p + p^{\uparrow} \longrightarrow \pi + X$$

Correlation proton spin S_p vs $p_{\pi\perp}$ π transverse momentum



Single transverse spin asymmetries A_N

$$A_N = \frac{N_L - N_R}{N_L + N_R}$$

Scaling Limit: $A_N \rightarrow 0$, QCD Test !?

VOLUME 41, NUMBER 25 PHYSICAL REVIEW LETTERS 18 DECEMBER 1978

Transverse Quark Polarization in Large-p_T Reactions, e^+e^- Jets, and Leptoproduction: A Test of Quantum Chromodynamics

G. L. Kane
Physics Department, University of Michigan, Ann Arbor, Michigan 48109

and

J. Pumplin and W. Repko
Physics Department, Michigan State University, East Lansing, Michigan 48823

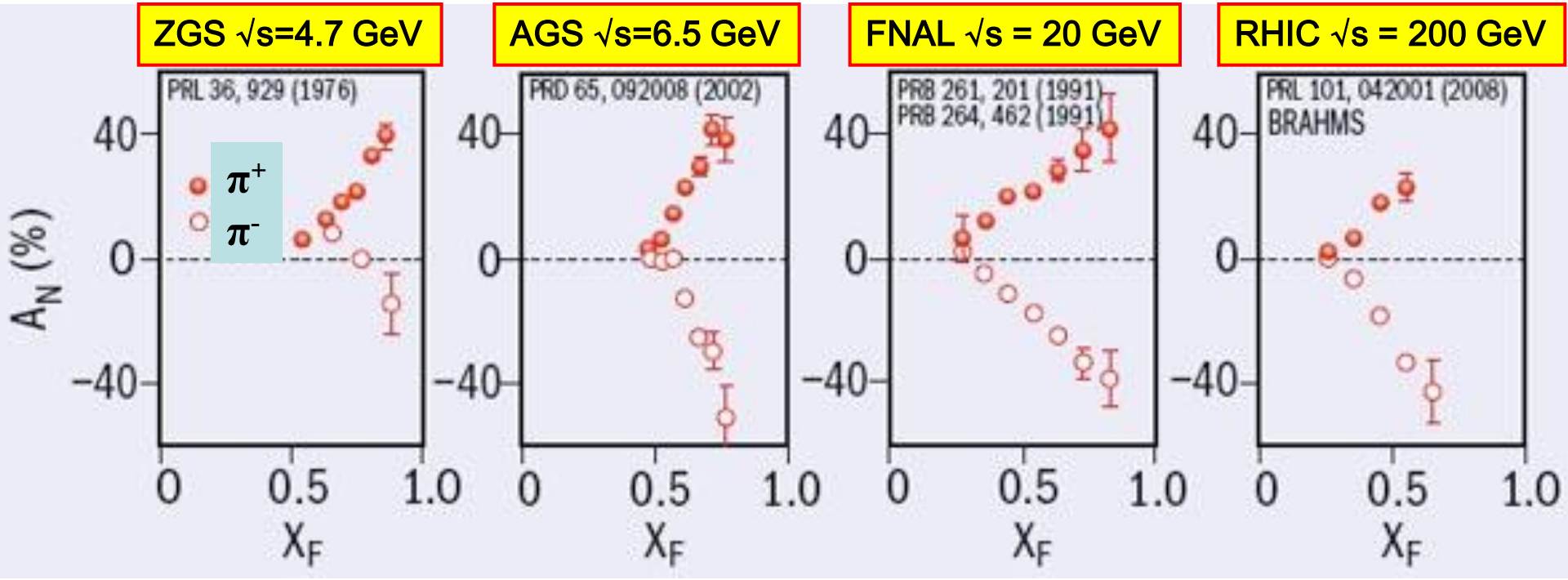
(Received 5 July 1978)

We point out that the polarization P of a scattered or produced quark is calculable perturbatively in quantum chromodynamics for $e^+e^- \rightarrow q\bar{q}$, large-$p_T$ hadron reactions, and large-Q^2 leptoproduction, and is infrared finite. The quantum-chromodynamics prediction is that $P = 0$ in the scaling limit. Experimental tests are or will soon be possible in $pp \rightarrow \Lambda X$ [where presently $P(\Lambda) \simeq 25\%$ for $p_T > 2$ GeV/c] and in $e^+e^- \rightarrow$ quark jets.

$$A_N \propto \frac{m_q}{\sqrt{s}} \quad \text{example, } m_q = 3MeV, \sqrt{s} = 20\,GeV, A_N \approx 10^{-4}$$

Experiment: Sizeable SSA Observed over Large Range of Scales !

Experiment: $A_N >> 10^{-4}$ for 4 GeV < √s < 200 GeV for charged pions !

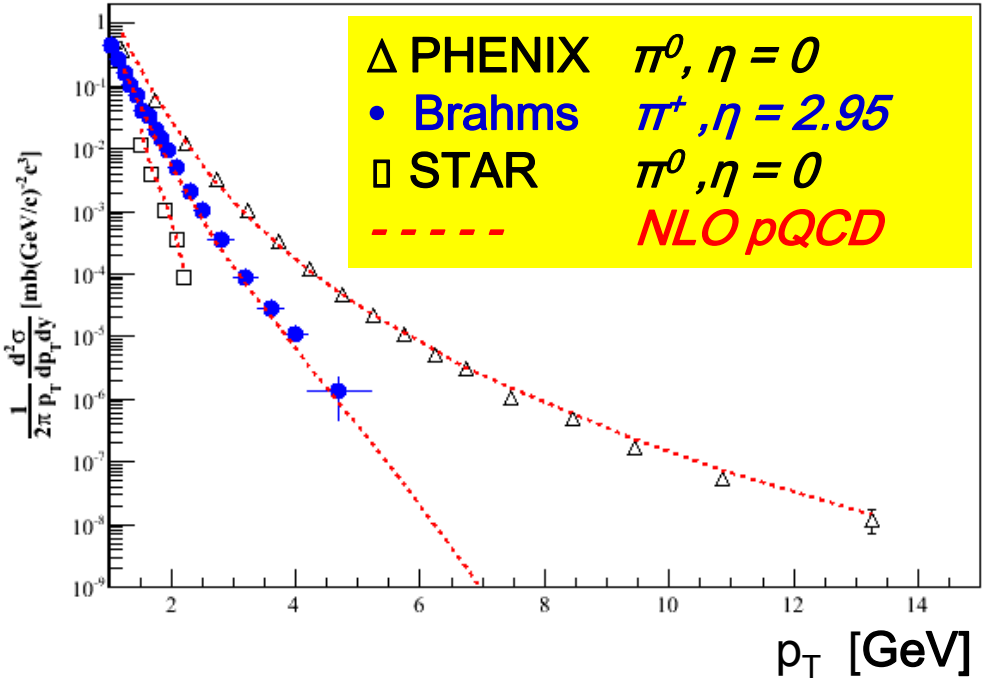


Soft effects due to QCD dynamics in hadrons remain relevant up to scales where pQCD can be used to describe the scattering process!

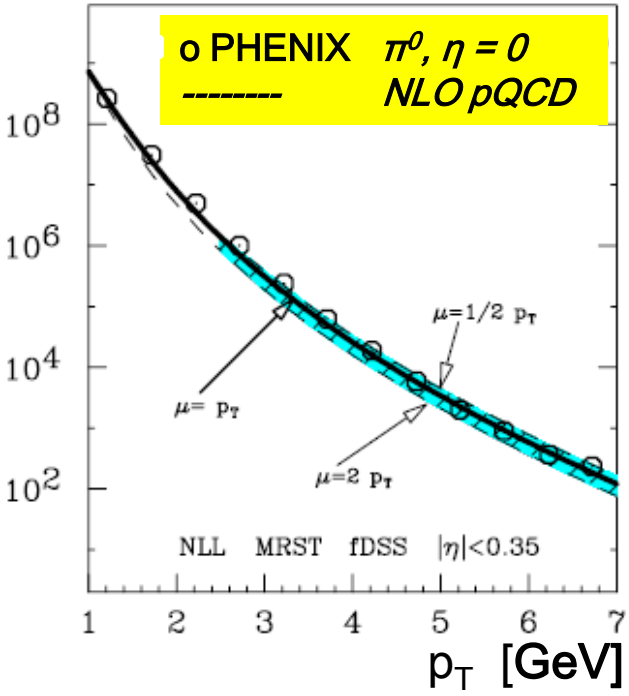
[from Christine Aidala, Spin 2008 and Don Crabb & Alan Krisch in then Spin 2008 Summary, CERN Courier, 6-2009]

NLO pQCD Cross Sections vs RHIC data for Different √s and Rapidity Intervals

√s = 200 GeV



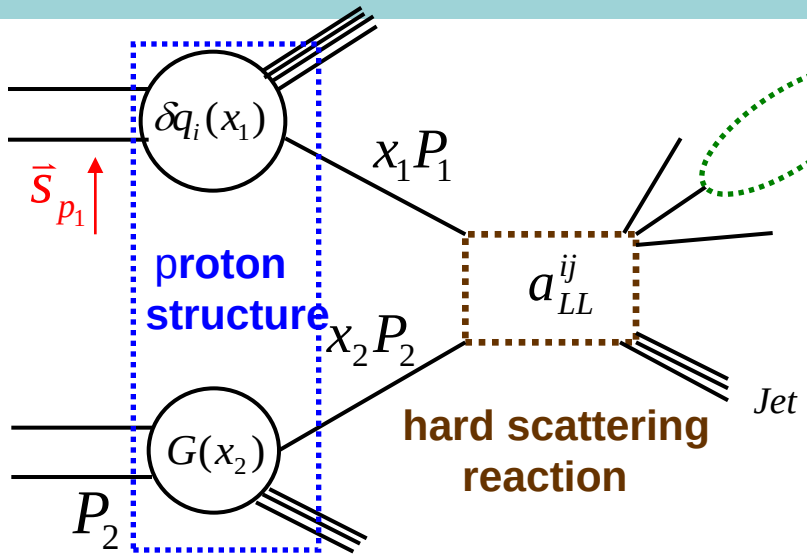
√s = 62.4 GeV



Good agreement between inclusive hadron cross sections from RHIC data and pQCD calculations !

See analysis in
De Florian, Vogelsang, Wagner
PRD 76,094021 (2007) and
Bourrely and Soffer
Eur.Phys.J.C36:371-374 (2004)

Origin of Large SSA → Inspect Cross Section in Factorized Form!



π^+

fragmentation process

Can initial and/or final state effects generate large transverse spin asymmetries? ($A_N \sim 10^{-1}$)

pQCD

$$\frac{d^3\sigma^{\uparrow}\left(pp^{\uparrow} \to \pi^+ X\right)}{dx_1 dx_2 dz} \propto q_i^{\uparrow}(x_1, k_{q,T}) \cdot G(x_2) \times \frac{d^3\hat{\sigma}^{\uparrow}(q_i q_j \to q_k q_l)}{dx_1 dx_2} \times FF_{q_{k,l}}(z, p_{h,T})$$

Initial state – proton structure

Kane, Pumplin, Repko → $a_{LL} \sim 10^{-4}$

Final state – hadron fragmentation

Origin of Large SSA for Hard Scattering -- Two Solutions: Final State vs Initial State

(I) "Transversity" quark-distributions and Collins fragmentation

Correlation between proton- und quark-spin and spin dependent fragmentation

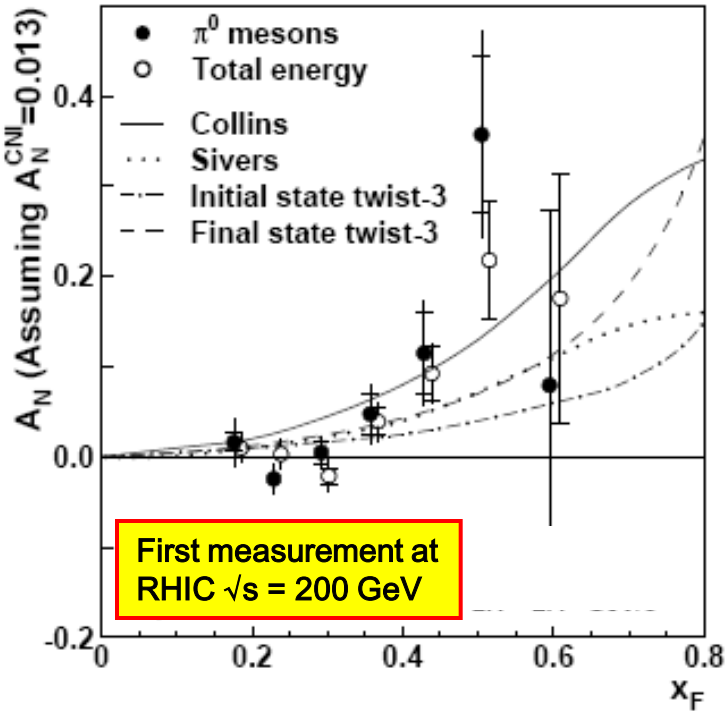
$$\propto \underbrace{\delta q(x)}_{\text{Quark transverse spin distribution}} \cdot \underbrace{H_1^{\perp}(z, p_{\perp}^2)}_{\text{Collins FF}}$$

(II) Sivers quark-distribution+

Correlation between proton-spin and transverse quark momentum

$$\propto \underbrace{\bar{f}_{1T}^{\perp q}(x, k_{\perp}^2)}_{\text{Sivers distribution}} \cdot D_q^h(z)$$

STAR, PRL-92:171801, 2004



(III) Initial or final state twist-3+

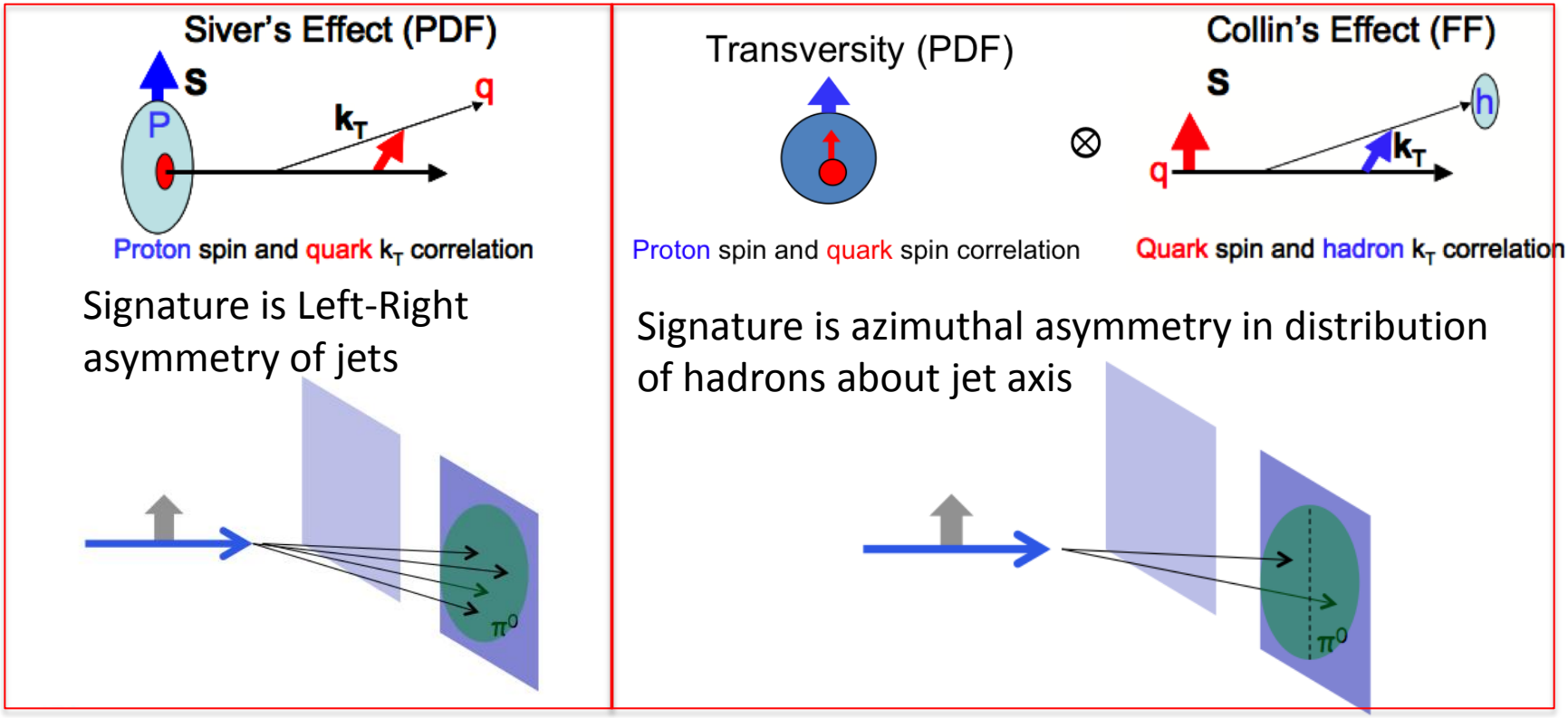
Qiu/Sterman and Koike

+ unified picture: Ji, Qiu, Vogelsang and Yuan in PRL-97:082002, 2006

Separating Collins and Sivers

- Source of large SSA seen at RHIC uncertain
- May be Sivers, Collins, or some combination

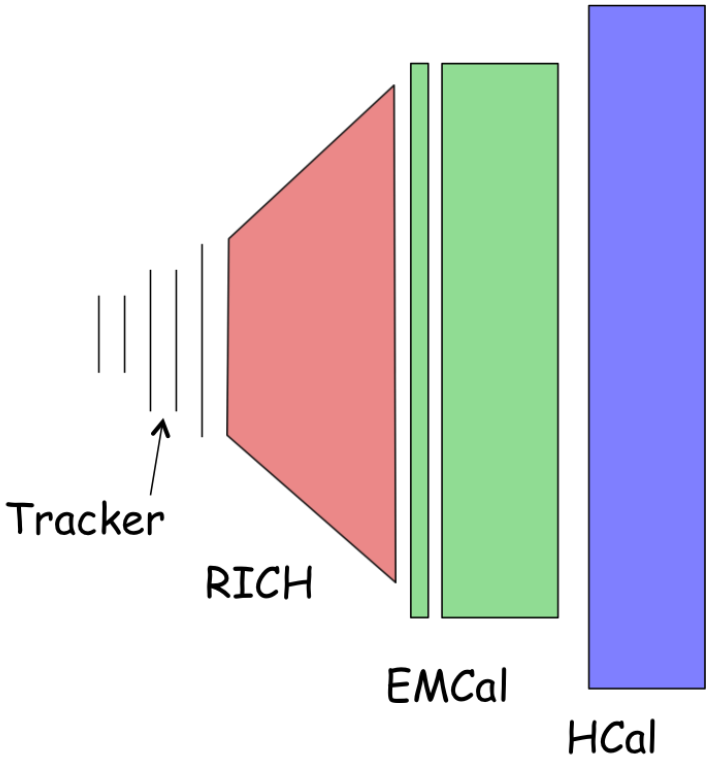
➜ Need to make measurements to separate them



from Kieran Boyle, DIS – April 2012

Experimental Requirements

- Good Jet reconstruction to be able to measure Sivers cleanly
  - Electromagnetic and hadronic calorimetry
- Particle ID to measure Collins effect
  - Collins effect different for different hadrons →RICH
- B Field and tracker to determine charge sign of hadrons



Separation of Sivers & Collins Effects : sPHENIX Observables

Inclusive Jet & gamma A_N ➔ Sivers PDFs reaching large x

A_T for hadrons within jets
and A_T for di-hadrons ➔ Transversity PDFs reaching large x

➔ Precise measurements of $h_{1T,q}$ (transversity) and $f^{\perp}_{1T,q}$ (Sivers) as function of x ➔ high x first in p-p forward measurements !

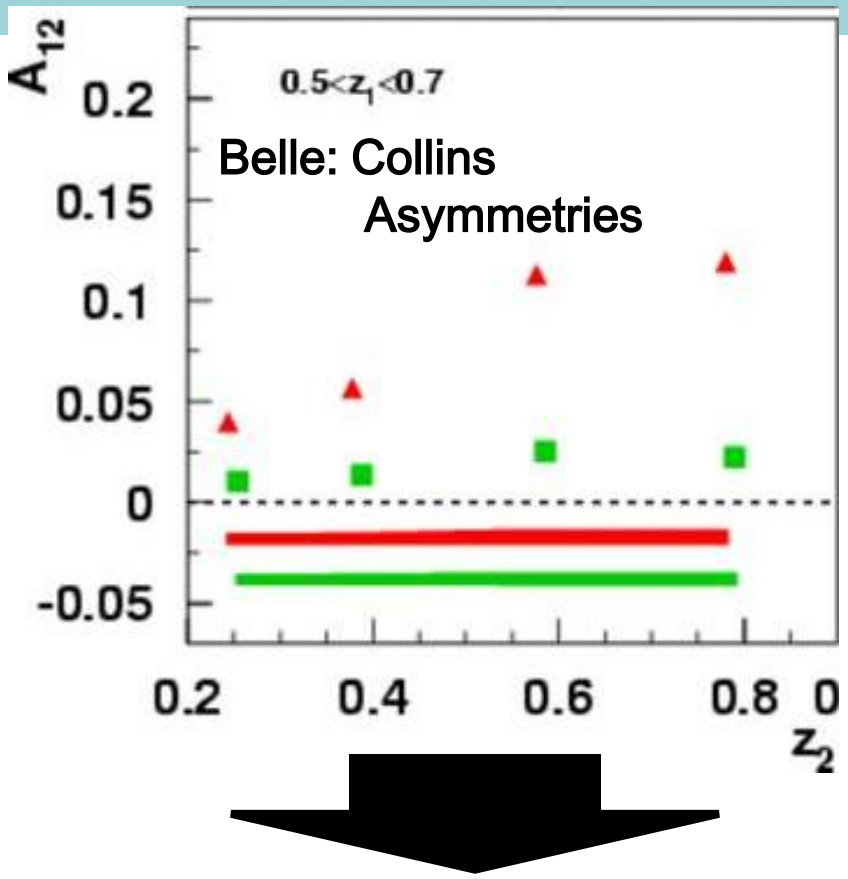
Knowledge of transversity quark distributions at large x is important for the extraction of the Tensor Charge

$$\sum_q \int dx \left[h_{1T,q}(x) - \bar{h}_{1T,q}(x) \right]$$

and its comparison to L-QCD predictions

Precise knowledge of Sivers distributions serves as input to establishing the connection between Sivers PDFs and orbital angular momentum.

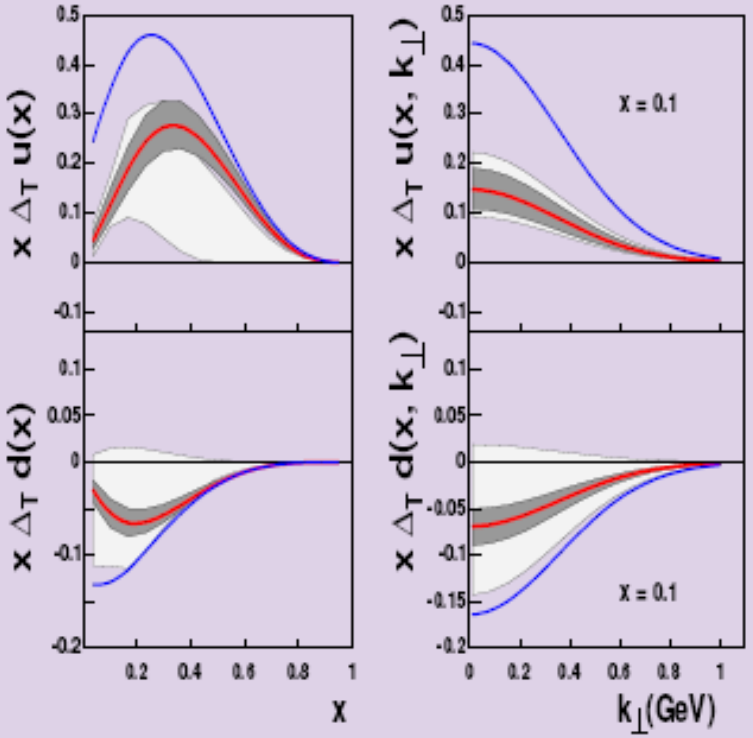
Status of Extraction of Quark Transversity Dis. and the Tensor Charge SIDIS+e^+e^-



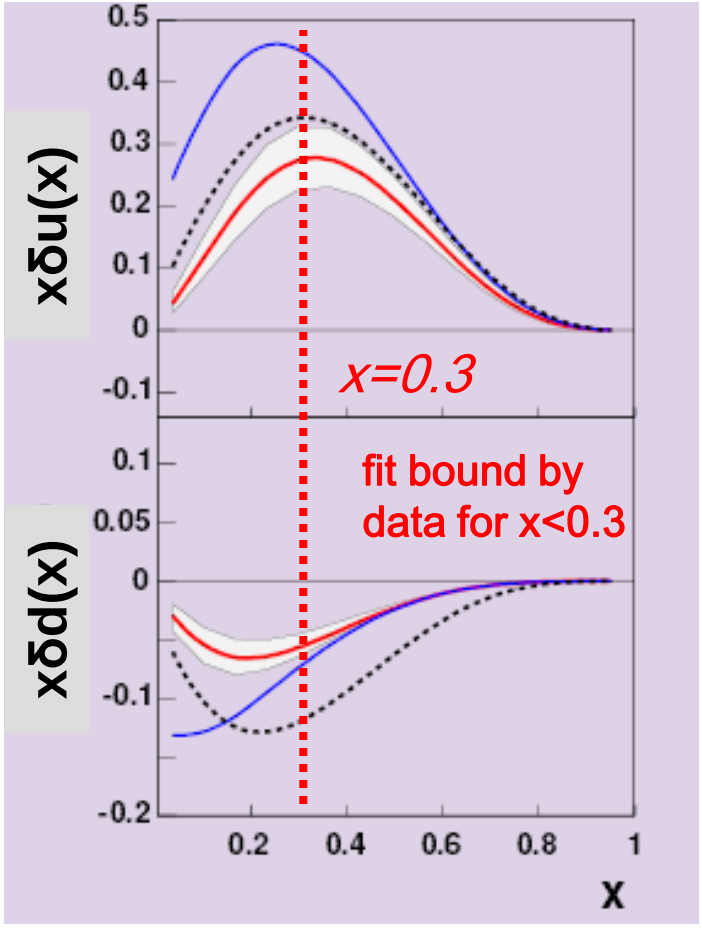
+ HERMES, & COMPASS data
➔ first extraction of δq(x) :

Anselmino, Prokudin et al.
Phys. Rev. D75:05032, 2007
Nucl. Phys. Proc. Suppl. 191, 2009

Extraction of Transversity
& Collins FF including errors !



About 40% of Tensor Charge = $\Sigma_{q=u,d}\int_0^1 h_{1T,}q(x)dx$
Bound by Data ➔ Extrapolation to Large x Important



Prokudin et al.

$\int h_{1T,u}(x)dx = +0.59^{+0.14}_{-0.13}$

$\int h_{1T,d}(x)dx = -0.20^{+0.05}_{0.07}$ at Q^2=0.8 GeV^2

Example for lattice QCD calculation

(M. Gockeler et al, Phys. Lett. B 627, 2005)

$\int h_{1T,u}(x)dx = +0.86 +/- 0.02$

$\int h_{1T,d}(x)dx = -0.22 +/- 0.05$ at Q^2=0.8 GeV^2

Can nucleon structure be described ab initio QCD with the help Lattice QCD?

sPHENIX contribution:
constrain tensor charge by measuring transversity at medium and high x!

Collins Extraction of Transversity: Model Dependence from Transverse Momentum Dependences!

transversity

Collins FF

$$A_{UT}^{Collins} = \frac{\sum_q e_q^2 \int d\phi_S d\phi_h d^2k_\perp \delta q(x,k_\perp) \frac{d(\Delta\sigma)}{dy} H_{1,q}^{\perp}(z,p_\perp) \sin(\phi_S + \phi + \phi_h) \sin(\phi_S + \phi_h)}{\sum_q e_q^2 \int d\phi_S d\phi_h d^2k_\perp q(x,k_\perp) \frac{d(\Delta\sigma)}{dy} D_q^h(z,p_\perp)}$$

quark pdf

hadron FF

$k_\perp$ *transverse quark momentum in nucleon*

$p_\perp$ *transverse hadron momentum in fragmentation*

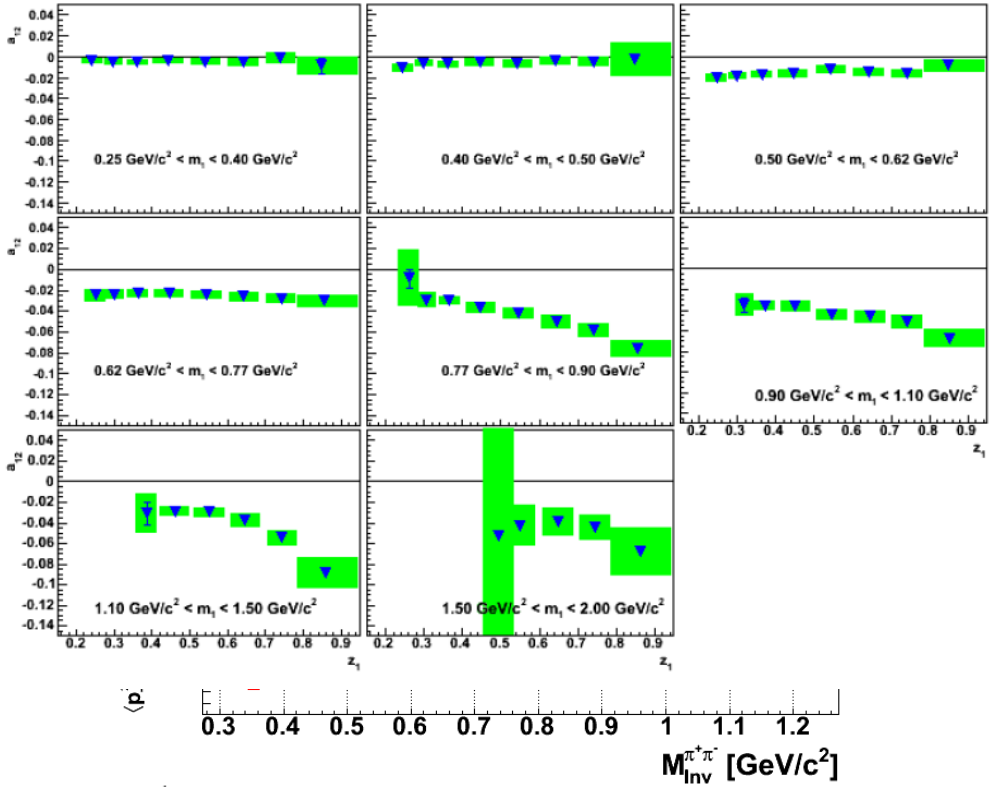
Anselmino, Boglione, D'Alesio, Kotzinian, Murgia, Prokudin, Turk Phys. Rev. D75:05032,2007

The transverse momentum dependencies are unknown and difficult to obtain experimentally!

IFF will provide alternative route of access independent of knowledge of transverse momentum dependencies.

sPHENIX IFF in p-p

Belle IFF asymmetries vs z for diff. $m_{h1,h2}$



Belle IFF results have been published in PRL.

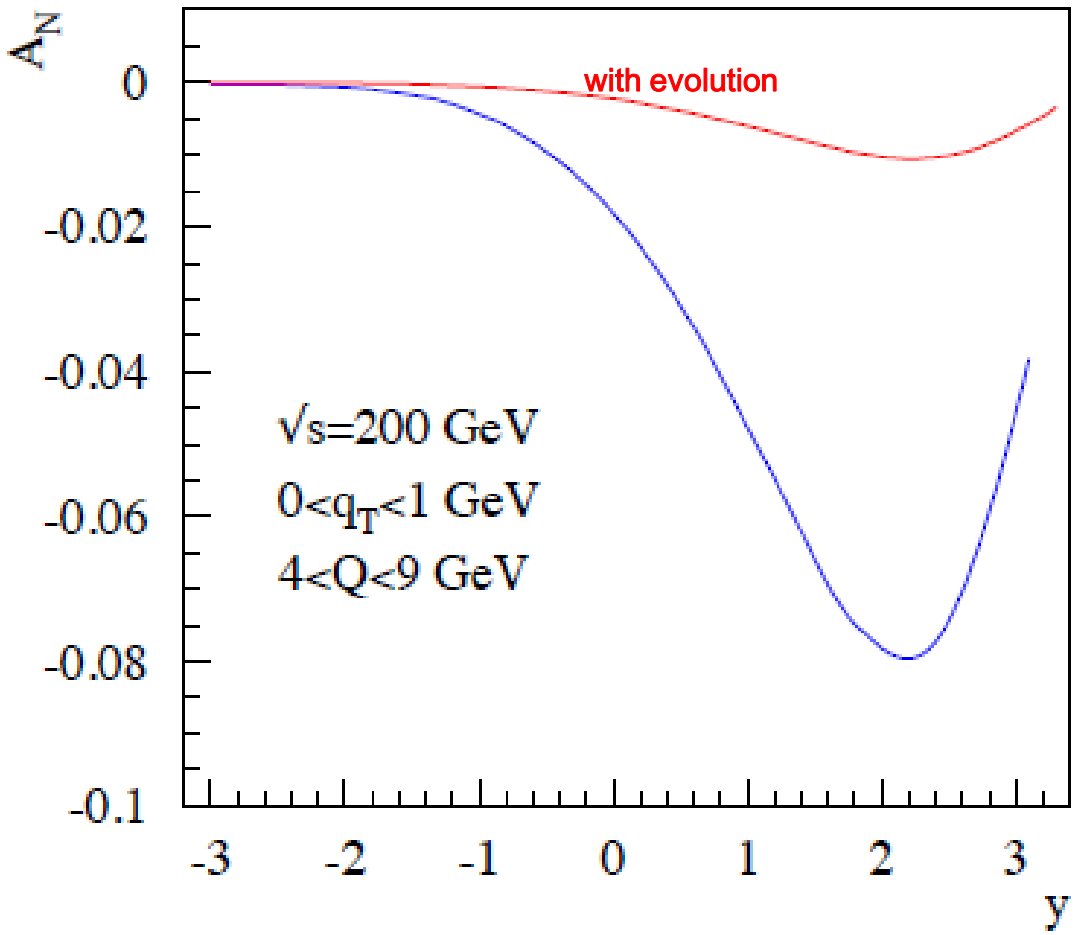
New STAR IFF !

s-PHENIX offers forward measurements reaching high x with good PID, larger analyzing power and higher statistics

Best access to transversity & tensor charge!

Comparison of Collins- and IFF extractions tests concepts of evolution and universality for TMDs.

A_N Drell-Yan → Test of TMD Framework



Gauge link integrals
In initial state in SIDIS and final State in Drell-Yan

$f_{\perp 1T,q}$ (SIDIS) = - $f_{\perp 1T,q}$ (Drell-Yan)

New results on TMD evolution leads to smaller DY Sivers asymmetries.

➔test predictions for process dependence and evolution

➔both a very important for the extraction of Transversity and Sivers distributions from the data!

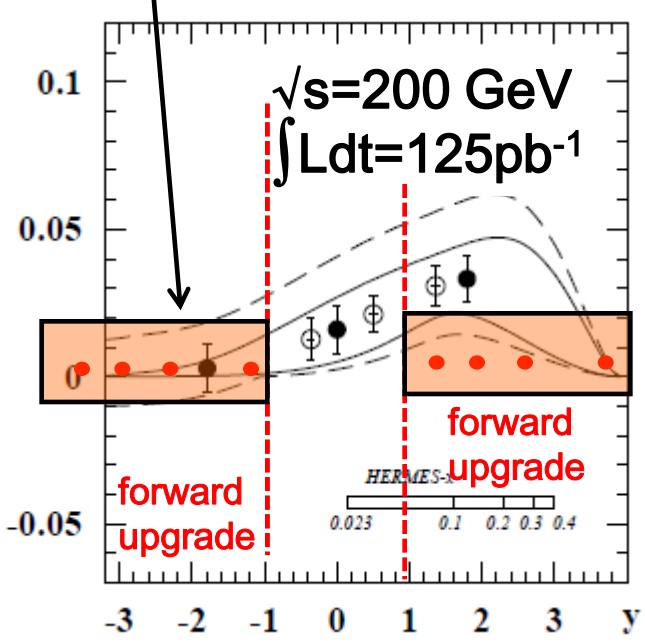
A_N Drell-Yan Sensitivity for Sea and Valence Quark Sivers Distributions

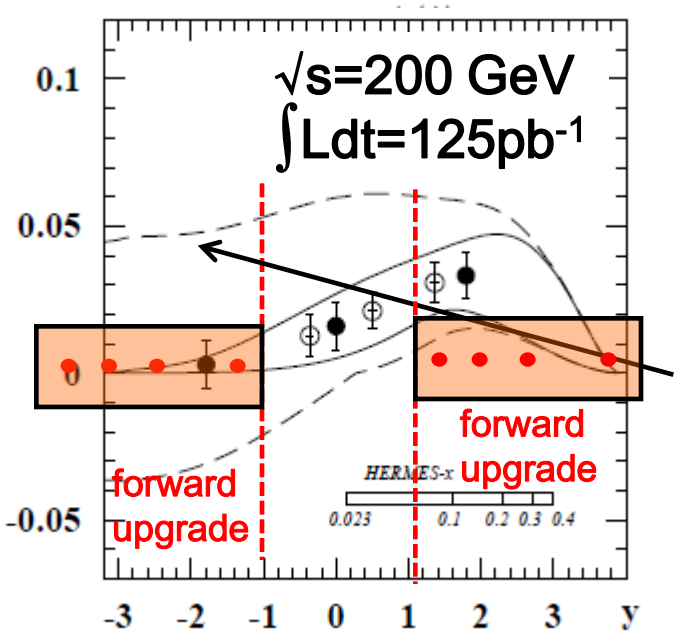
(I) Sivers sea distributions scale as the valence Sivers distributions

unique access to sea-quark Sivers dis. through DY in backward direction

$$f_{1T_{\rm DY}}^{\perp(1)\bar{q}}(x) = \epsilon(x)\ f_{1T_{\rm DY}}^{\perp(1)q}(x)$$

$$\epsilon(x) = \pm \begin{cases} 0.25 = \text{const} & \text{model I} \\ \dfrac{(f_1^{\bar{u}} + f_1^{\bar{d}})(x)}{(f_1^{u} + f_1^{d})(x)} & \text{model II} \end{cases}$$





(II) Sivers sea distributions scale as the unpolarized sea quark dis.

Collins, MGP et al. PRD 73 (2006) 090

projections to be made

A_N Drell-Yan: Competition

Drell-Yan + GPD physics from 2014

Drell-Yan physics proposals pending

Drell-Yan + J/ψ physics from 2014

Drell-Yan physics from 2020 (PANDA)

SeaQuest proposal for polarized target by 2014

A-Dependence of Nucleon Structure ➔ Goals

p-A (I) Study the transition region near the saturation scale!

(II) **Measure $G_A(x)$ and quantify initial state for HI collisions at RHIC: heavy flavor, jets, jet-correlations, direct photon, Drell-Yan, different nuclei, beam energy.**

(III) **Search for onset of gluon saturation and verify CGC framework as an effective field theory at high field strengths in QCD.**

For example: can we determine color configurations $W(\rho)$ from RHIC data and use the JIMWLK evolution to evolve them to LHC energies?

(IV) Explore similarities between TMD and CGC formalisms.

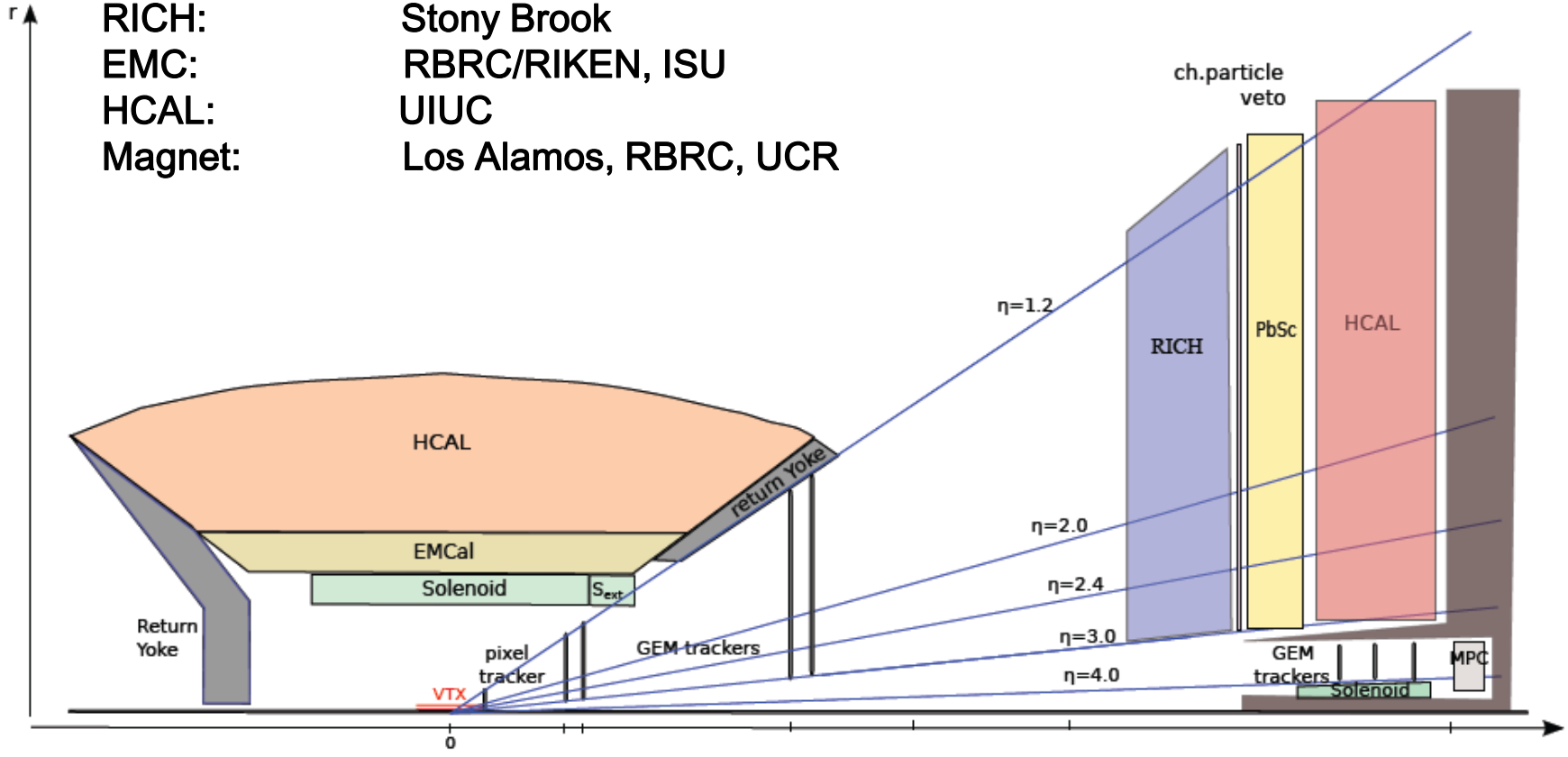
Next Steps

- Detector and sensitivity simulations in progress
- RBRC workshop on "Forward Physics at RHIC"
  → July 30 to August 1st 2012
- Initiate exploratory R&D
  - GEM-trackers at Los Alamos (LDRD)
  - EMC at RBRC (RIKEN)
  - HCAL at UIUC (NSF)
- Report on Physics and Design Studies
  → November 2012
- Explore funding possibilities: external funds, staging

Detector Layout for Physics Studies

Studies for detector components led by

GEM-trackers: Los Alamos, RBRC
RICH: Stony Brook
EMC: RBRC/RIKEN, ISU
HCAL: UIUC
Magnet: Los Alamos, RBRC, UCR



Summary

- PHENIX has started to evaluate the physics potential of a large acceptance sPHENIX forward detector for Drell-Yan and jet physics in polarized p-p, p-A and A-A collisions.
- Precision measurements with clean theoretical interpretation would become possible:

  Saturation physics, survey of the Sivers function, transversity distributions, tensor charge and tests of the evolution of transverse momentum dependent observables.
- Significant effort and care will be needed to meet the experimental and theoretical challenges: high luminosity + polarization, high performance detector, precision polarimetry, tools for the clean pdf extraction.
- We seek to utilize existing equipment as much as possible and to solicit substantial external funding sources.

Incomplete List of PHENIX Spin Collaborators who have Expressed Interest in the Forward Upgrade

Abilene Christian University, Abilene, TX 19973, USA
M. Daugherty, D. Isenhower R.Towell

Brookhaven National Laboratory, Upton, NY 11973, USA
S. Bazilevsky, M. Chiu

University of California, Riverside, Riverside, CA 92521, USA
K. Barish, R. Seto

CIAE, Beijing, China
X. Li

Georgia State University, Atlanta, GA 30303, USA
X. He, M. Sarsour

Hanyang University, Seoul 137-791, Korea
B. Kang, J. Kang, Y. Kim, B. Park

University of Illinois, Urbana, IL 61801, USA
M. Grosse Perdekamp

Iowa State University, Ames, IA 50011, USA
J. Hill, J. Lajoie

KEK, Tsukuba, Ibaraki,305-0801, Japan
N. Saito

Korea University, Seoul, 136-701, Korea
B. Hong, K. B. Lee, S. Park

Los Alamos National Laboratory, Los Alamos, NM 87545, USA
M. Brooks, M. Liu, X. Jiang, M. Leitch

Muhlenberg College, Allentown, PA 18104, USA
B. Fadem

New Mexico State University, NM 88003 USA
S. Pate

University of New Mexico, Albuquerque, NM 87131, USA
D. Fields

RIKEN Brookhaven Research Center, Upton, NY 11973, USA
J. Seele, K. Okada

RIKEN Institute, Hirosawa, Wako, 351-0198, Saitama, Japan
Y. Goto, I. Nakagawa, R. Seidl

Rikkyo University, Rikkyo, 3-34-1, Tokyo, 171-8501, Japan
K. Kurita and J. Murata

Seoul National University, Seoul, Korea
K. Tanida

Stony Brook University, Stony Brook, NY 11970, USA
A. Deshpande, K. Dehmelt, T. Hemmick

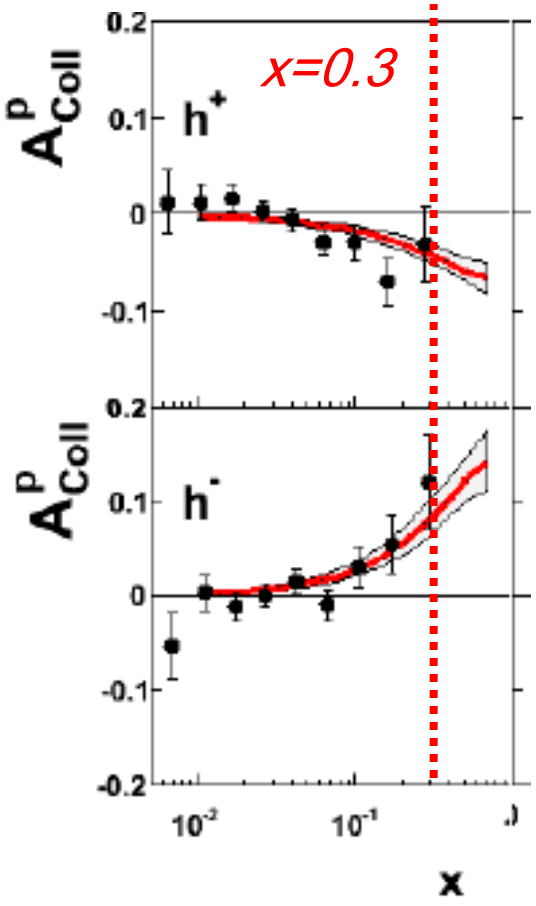
University of Michigan, Ann Arbor, MI 48109, USA
C. Aidala

20/14 institutions from the US, China, Korea and Japan

collaborators presently active in forward upgrade planning & studies, coordinators

Comparison of HERMES + Belle Based Prediction for COMPASS to Data

COMPASS Collins Asymmetries for Proton Target
vs predictions from Anselmino, Prokudin et al.



Good agreement of COMPASS proton data with preditions from fit to HERMES, COMPASS-d +Belle. Important cross check as COMPASS is at higher Q^2!

However, no data at x > 0.3 …

➔$h_{1T,q}(x)$ not bound at large x

➔uncertainty in tensor charge